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Longitudinal assessment

Differences over a decade: high tech capabilities and competitive performance of 28 nations

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People often look to technology-based advancement as the key to achieving and maintaining economic competitiveness. This belief often resonates through national policy at the highest levels. Does investing in high technology really provide a competitive advantage? Since 1986, researchers at Georgia Tech's Technology Policy and Assessment Center have been systematically monitoring national high technology-based industrial competitiveness to help address this question. This paper reports on a longitudinal assessment of high technology capability and resulting competitive standing across 28 countries from 1993 through 2003.

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PEOPLE OFTEN TOUT high tech advancement as the key to achieving and maintaining economic competitiveness. This belief drives national policies toward developing infrastructure in support of a country's technological position. Does investment in these infrastructural elements help achieve a competitive position among nations (c.f. OECD, 2000; Archibugi *et al*, 1999)? Since 1986, researchers at Georgia Tech's Technology Policy and Assessment Center have been monitoring national high technology-based industrial competitiveness to help address this question. The monitoring process, conducted every three years, compiles a series of current and forward-looking 'high tech indicators' (HTI) that assess a nation's competitive stance. The multifaceted indicators, composed of statistical and survey-based elements, assess four 'inputs' — infrastructure elements — and a key 'output' — global market position element. The structure and formulation of the indicators stabilized in 1993 and the time series now supports longitudinal analysis across 28 countries. These countries range from G-8 nations, to newly industrialized economies, to mid-tier countries. We report here on the changes in indicators of national capabilities and in performance between 1993 and 2003.

Background

Worldwide attention to technological innovativeness and competitiveness indicators is increasing dramatically (c.f. Clark and Guy, 1998; Grupp, 1995). Accordingly, interest in science and technology

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(S&T) indicators is increasing (c.f. Sirilli, 1997; Porter and Stern, 1999; van Raan, 2000). This is especially prevalent in Europe with the development of the Innovation Scoreboard (OECD, 1999), the Entrepreneurship Scoreboard, and so forth <http://www.cordis.lu/innovation-smes/scoreboard/home.html>. However, the prominent European and OECD indicators (c.f. Godin, 1996) do not cover the industrializing countries effectively and use of their measurements within emerging economies poses challenging issues.

The need to address *emerging economies* (Mani, 2000) is key to the Georgia Tech approach. The rapid change experienced by industrializing economies provides interesting observation points to clearly see how investment produces payoff. At its inception, the HTI series was designed to focus on the Asian 'Tigers' and 'Cubs' (c.f. Rausch, 1995). Tracking their emergence was essential to understand shifting patterns in world trade. Any nation that seeks to derive major economic power from high technology-based exports needs to recognize what is happening in emerging economies that are using high tech as an engine to drive economic growth.

There are data sources that do cover industrializing economies. These include:

- The World Bank's *World Development Report* <http://econ.worldbank.org/wdr/wdr2003/>
- *The World Competitiveness Yearbook* <http://www01.imd.ch/wcy/>
- The World Economic Forum's *Global Competitiveness Report* <http://www.weforum.org/site/homepublic.nsf/Content/Global+Competitiveness+Programme>
- The UN Commission on Science and Technology for Development (CSTD) and the UN Conference on Trade and Development (UNCTD) reach out farther in seeking to devise technological competitiveness and information and communications technology (ICT) indicators for most countries <http://r0.unctad.org/stdev>.

Unfortunately, most of the sources tend to report individual statistics. With the exception of the *Global Competitiveness Report*, few sources attempt to synthesize individual data elements within an overall context of competitiveness or development.

At the core of the HTI indicators is an underlying conceptual model of competitiveness and development. This model views international economic competitiveness as a multidimensional issue. Competitiveness encompasses everything from policies of national governments and attitudes of citizens to investments in infrastructure and manufacturing capability. This model is forward-looking. It assumes that a country must make investments today to obtain high technology capacity in future years. The structure of the model was developed and refined during a series of projects at Georgia Tech starting in 1986. The model is based on the idea that successful technology absorption and use requires that a nation have the intent, or will, to become more competitive internationally in technology-based markets, and possess the resource, or capacity, to implement that intention. The model contains four main elements: *national orientation, socioeconomic infrastructure, technological infrastructure* and *productive capacity*. The specifics of the model and discussion of what factors drive competitiveness are covered in detail by earlier publications (Roessner *et al*, 1992; Porter *et al*, 1996).

Our operating assumption within the model is that the four key infrastructure components influence long-range (that is, roughly, 15-year) technology-based export performance. One should stress this 15-year lag is an initial assumption and a reflection of our desire to design a forward-looking model. We know that most of the input factors take time to create an impact. We suspect that some factors cause an impact on competitiveness faster than other factors. We also accept that factors interact with each other during the process. We have yet to characterize the precise nature of the interaction and the precise nature of the time lags associated with the indicators. These issues are the targets of future study as we collect more data.

Although the model operates on an assumed 15-year time horizon, HTI indicators are attaining sufficient maturity to draw interesting comparisons across countries, regions (e.g. Southeast Asia, Latin America, Eastern Europe), and time (e.g. sharp upsurge seen for China recently). Recent HTI results have been described in several publications (Porter *et al*, 2001; Roessner *et al*, 2002; Porter *et al*, 2002; Porter *et al*, 2004). HTI currently tracks 33 nations:

- The 'Big Three' — United States, Japan and Germany
- Western Europe (UK, France, Netherlands, Italy, Switzerland, Sweden, Spain and Ireland)
- English Heritage Nations plus Israel (Canada, Australia, South Africa, New Zealand and Israel)
- Eastern Europe (Russia, Poland, Hungary and Czech Republic)
- Asian Tigers (Singapore, South Korea and Taiwan)
- Asian Cubs (Malaysia, China, Thailand, Indonesia, Philippines and India)
- Latin America (Mexico, Brazil, Argentina and Venezuela).

However, certain of the countries have been added to the series since 1993, so are not addressed here: Czech Republic, Ireland, Israel, Poland and Venezuela. We presently address findings for the remaining 28 countries.

Methods

HTI combines *statistical measures* (c.f. Van Raan, 1988), compiled from a number of sources, with *expert opinion* gathered from our International

Indicators Panel. We combine these to compose 'indicators' for the target input and output factors. The expert opinion items compensate for statistical gaps to cover essential components of the model for high-tech based competitiveness. Recent HTI summary reports, along with the survey instrument and an appendix that specifies the components of our 'Input' and 'Output' indicators in detail, are available <http://tpac.gatech.edu> (Porter *et al*, 2003).

Our four input indicators consist of:

- *National orientation* (NO): Evidence that a nation is undertaking directed action to achieve technological competitiveness. Such action can be manifested at the business, government or cultural levels, or any combination of the three. The indicator consists of a statistical measure of investment risk, and survey questions addressing national strategy, implementation, entrepreneurship and attitudes toward technology.
- *Socioeconomic infrastructure* (SE): The social and economic institutions that support and maintain the physical, human, organizational and economic resources essential to the functioning of a modern, technology-based industrial nation. The indicator consists of a statistical measure (Harbison–Myers Human Skills Index) and survey questions addressing national policies toward multinational investment and mobility of capital.
- *Technological infrastructure* (TI): Institutions and resources that contribute directly to a nation's capacity to develop, produce and market new technology. Central to the concept are the ideas of economic investment and social support for technology absorption and utilization. These could take the forms of monetary payments, laws and regulations, and social institutions. Also included is the physical and human capital in place to develop, produce and market new technology. The indicator consists of statistical measures of the number of scientists in R&D and electronic data processing purchases and survey questions addressing technical training and education, contributions to knowledge, R&D with industrial relevance and technological mastery.
- *Productive capacity* (PC): The physical and human resources devoted to manufacturing products, and the efficiency with which those resources are used. The indicator consists of a statistical measure of electronics production and survey questions addressing supply of skilled labor, indigenous component supply, and indigenous management capability.

For most of the results herein presented, we combine these four additively to give an overall 'INPUT' score.[1] Over the years we have experimented with many alternative formulations (Porter *et al*, 1991). Indeed, our model favors a multiplicative formulation (i.e. that weakness in any one infrastructure element will greatly reduce resulting competitiveness). However, the behavior of the additive model closely tracks that of the multiplicative alternative and is more robust (less sensitive to extreme values in the components). Individual input indicators are broken out in the HTI 2003 summary report available at the website <http://tpac.gatech.edu>.

The one output indicator we emphasize here is:

- *Technological standing* (TS): Reflects current high technology product export performance. The indicator consists of statistical components measuring the value of high tech exports and the value of electronics exports and a survey question addressing current high technology production capability.

Note that this and the input indicators include statistical measures that range drastically from smaller to larger economies. In addition, they incorporate expert opinion measures on five-point scales that are far less sensitive to the scale of an economy. That said, HTI are not *per capita* measures; they concern national economic competitiveness as such. Technological standing (TS) does tend to mute the huge differences from the largest technology-based exporters (USA, Japan) to smaller economies. This reflects its incorporation of one expert opinion measure addressing current high tech production along with two statistical measures (concerning high tech exports and the value of electronics exports).

The component measures that constitute each indicator are scaled from 0 to 100. These 'S-scores' range from a minimum (zero or lowest scale value) to a relative maximum (100 = value of the highest of the set of countries on that component). This enables reasonable combination of our expert opinion items (scaled initially from one to five) together with our statistical measures that can differ in range by orders of magnitude. S-scores are also easily comprehended. A small difference is also introduced in that the set of countries expands from 28 to 33 from 1993 to 2003. However, the added countries are generally not at the component extremes, so that the S-scores would be highly stable were we to recalculate these based on just the 28 countries for 2003. We do not choose to do so to avoid confusion in other comparisons for 2003.

Beginning in the late 1980s, we have worked together with US National Science Foundation

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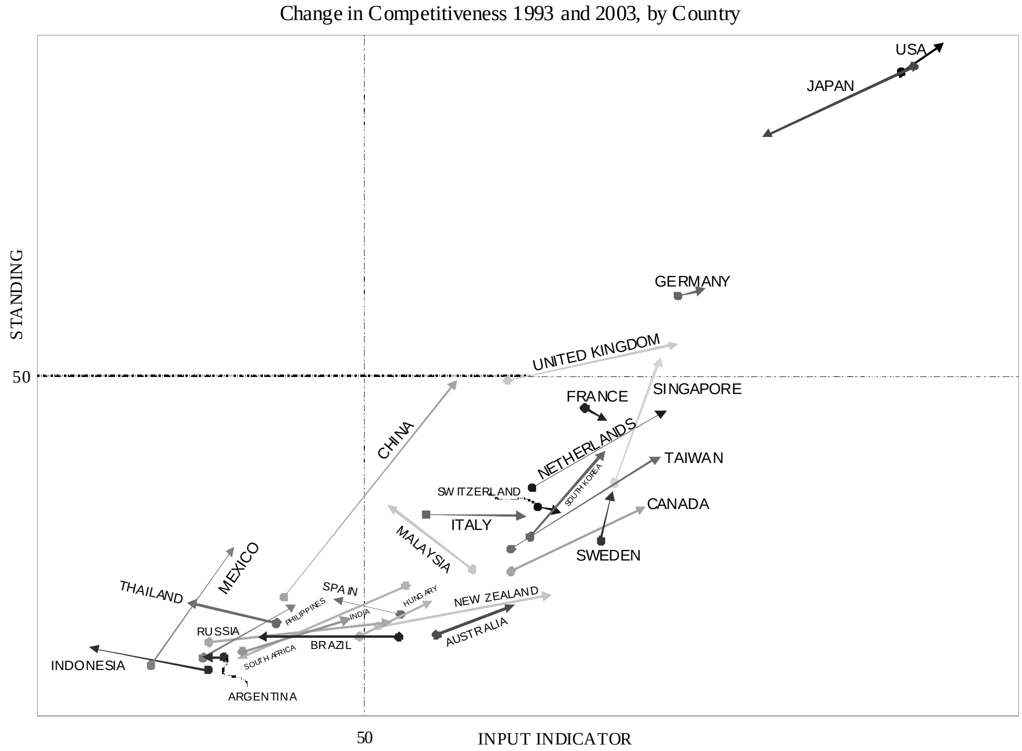

Figure 1. Relative change in national high tech infrastructure (input indicator) and performance (standing)

colleagues to invite selected professionals to serve on the International Technology Indicators Panel. Our criteria include direct knowledge of the country and of the bases for technological competitiveness. Prototypical experts include embassy science attachés, faculty members and industrial professionals. Attendees at international conferences and participants in journal advising and publishing relating to technology analysis, forecasting, management and so forth are good candidates for the panel. We seek balance among multiple perspectives, and between indigenous and external 'watchers'.

Over time, turnover in membership has been heavy — only 31% of the current respondents also participated in 1999. We invite various persons who appear to meet these criteria to participate, but ultimately self-selection comes into play. The respondents indicate their familiarity on a self-report scale item. The '2003' data were obtained during summer and fall, 2002. Surveys were largely completed through a website interface <http://tpac.gatech.edu/>, augmented by email, fax and mail contacts. The resulting group of 371 experts collectively provided 412 responses. The average number of responses per country was 12.5, with a minimum of 10 per country.

The referenced reports on HTI explore changes in these indicators over time. They also investigate the association of 'input' factors ('drivers') to 'outputs' (technology-based products and services). Such relationships are not straightforward (Roessner *et al*, 2001). We note that our HTI model postulates that our input factors portend changes in technology-based export competitiveness roughly 15 years later. Thus our data are just barely attaining sufficient duration to assess the HTI predictive powers. Early results suggest limited predictability, with TI and PC better predictors than NO and SE (Porter *et al*, 2001).

National high tech indicators profiles

We focus first on a revealing depiction of HTI results. Figure 1 shows a scattergram of all of our countries for which we have data spanning the period 1993–2003.[2] This plots:

- X-axis: the composite INPUT indicator values for 1993 and 2003
- Y-axis: TS — technological standing for 1993 and 2003.

The axes range from 0 to 100, with the middle value, 50, used to create four quadrants. The values are connected by an arrow running from 1993 to 2003. This shows the direction of change.

Note that these S-score measures are composites and they are relative. In other words, the decline in Japan's values *does not* mean an absolute decline in the underlying components for Japan, just a lower position relative to the leader on the measures. Japan's high tech and electronics exports actually increased over this period, but not quite proportionately to the leader. Also recognize that our indicators are based on a set of highly competitive countries, so ‘weak’ showing is again only relative. You may also note that not all highly developed countries appear. HTI does not include every OECD country because its primary focus is on the industrializing economies. We do not present precise scaling in the figures so as to emphasize patterns and changes, not precise values. Numerical indicator values are available at <http://tpac.gatech.edu>.

An argument could be made that one TS component, high tech exports, is the ‘real’ output target. The disparities in high tech exporting are huge (Table 1).

Below the countries in Table 1, the next 10 nations range from $US16 billion to $US44 billion in high tech exports. The next 13 nations range from $US0.3 billion to $US10 billion. So, the range in high tech exporting in this elite group of 33 nations is from less than US$0.4 billion to US$263 billion.

With these cautions in mind, the figures provide some fascinating results. First consider in terms of our country groupings:

- *The ‘Big Three’ — United States, Japan and Germany* When HTI began, in the late 1980s, West Germany was closer to the USA and Japan, and more distant from the other countries. Since then, probably due considerably to the incorporation of East Germany, high tech export competitiveness has been more of a ‘Big Two’. Nonetheless, for this recent decade, Germany shows progress on INPUT and a bit on TS (standing) as well. We discuss further below.
- *Western Europe (UK, France, Netherlands, Italy, Switzerland, Sweden, Spain and Ireland)* Ireland is not included, having been added since 1993. Of this group, note the nice gains by the UK and The Netherlands. Italy has increased on INPUT; time will tell if this is reflected in eventual output (export competitiveness) gains.
- *English Heritage Nations plus Israel (Canada, Australia, South Africa, New Zealand and Israel)* Israel, another dynamic, small economy, was added since 1993, so is not shown. Canada, Australia and New Zealand show strong advances on both INPUT and TS. South Africa shows the worst trajectory of all the countries plotted.

Table 1.‘Top 10’ high tech exporters for 1999 (in US$ billions)

1	USA	263
2	Japan	161
3	Germany	139
4	UK	104
5	France	87
6	Singapore	74
7	Netherlands	56
8	China	54
9	South Korea	54
10	Malaysia	51

- *Eastern Europe (Russia, Poland, Hungary and Czech Republic)* Poland and the Czech Republic do not appear because they were added after 1993. Russia shows strong gains, particularly in INPUT.
- *Asian Tigers (Singapore, South Korea and Taiwan*) The Tigers show tremendous economic strides. When HTI began, these were the ‘newly industrializing countries’. Compare their standing (TS) in technology-based export competitiveness to the Western European countries. If you were looking to cluster similarly performing economies, you might lump together the UK, Singapore, France, The Netherlands, Taiwan and South Korea. This would have been hard to imagine back in 1987! Note that the similarities extend to INPUT as well as TS. We do note that TS emphasizes electronics, a particular strength of the Tigers but, nonetheless, all now recognize this shift in technology-based economic power toward Asia.
- *Asian Cubs (Malaysia, China, Thailand, Indonesia, Philippines and India*) The cubs have a mixed set of results. China improved greatly while others, like Malaysia, Thailand and Indonesia, increased their global standing while their inputs declined.
- *Latin America (Mexico, Brazil, Argentina and Venezuela*) Venezuela was added since 1993. Mexico is the only standout of the group showing strong increases in both inputs and standing.

Note the change in position of Japan and the USA. In 1993, they were very close to each other on both INPUT and TS, with Japan slightly ahead on both. A decade later, the USA has increased on both indicators, while Japan has declined on both. Since 1993, Japan and the USA remain well ahead of all others in high tech competitiveness; however, the USA has forged a 12-point S-score lead over Japan. The US advance traces back to marked gains on overall high tech exports and on electronics exports; strangely, the USA still trails Japan on the expert opinion measure.

The elevation of Singapore’s position since 1993 is remarkable, particularly in that two of the three components that make up TS are absolute (not *per capita* or otherwise normalized) measures of electronics and high tech exports. Its high tech exports are primarily electronics, so our inclusion of electronics exports as a separate component of TS certainly benefits Singapore. No matter — Singapore’s US$74 billion in high tech exports ranks sixth in the world on an absolute basis even after removing re-exports (TS draws upon 1999 export data, the most recent available).

Other nations spread out greatly on the TS measure, generally changing modestly since 1993. The striking exceptions are China, which has greatly advanced its position on all indicators, and Mexico, which also shows remarkable advancement.

However, some countries scaled back their emphasis on high tech and still improved their global position in high tech markets. Malaysia exemplifies this trajectory, declining in many forward-looking indicators while still increasing its global market standing. Several countries saw a decline in forward-looking indicators as well as current standing. Venezuela fits this trajectory, declining across all these composite measures relative to the other 32 countries in the dataset. And finally only one country — France — saw an increase in forward-looking indicators combined with a slight decline in standing. This intriguing behavior perhaps raises some interesting issues related to the effectiveness of investments.

In the late 1980s, the Asian Cubs and Latin American countries were the two prominent sets of industrializing economies. Brazil's trajectory would not have been anticipated by our model. This suggests the model is probably not rich enough to 'advise' policy on its own (no surprise). In Brazil's case, changes in competitive policy (ending a protectionist approach), compounded with monetary and social issues, have somehow resulted in no gain in TS (again, these are relative measures). However, the decline in Brazil's INPUT suggests that those in power might want to analyze what is happening more deeply. Likewise, Argentina's position bears examination.

In contrast, Mexico has risen from a weak TS and weak INPUT position in 1993. Gains on both are encouraging. Special ties with the USA certainly affect Mexican technology-intensive exports beyond what a general model could capture.

The variety of trajectories emphasizes the complexity of forming the role of high tech in national competitiveness. When looking at a nation in isolation, it is easy to mentally model the impact of high tech on competitive effectiveness. However, when one puts that model in motion across many countries, the interrelationships become complex. This preliminary assessment points to:

- Countries in strong high tech positions that continue to invest heavily in precursor infrastructures can make their market positions virtually unassailable.
- Countries can 'coast' on previous investments for substantial lengths of time.
- Countries with weak market position can make substantial advances with investments in high tech precursors.
- Countries can get it wrong. They can make investments and still get few results.

Indictors can play a vital role in helping researchers and policy-makers assess and understand the complex interplay among investments and hi-tech performance

Stepping back and looking ahead

Indictors can play a vital role in helping researchers and policy-makers assess and understand the complex interplay among investments and hi-tech performance. When the Georgia Tech high tech indicators development was initiated in the mid-1980s, a small clique of technologically advanced nations dominated. The sense in profiling a country set including newly industrializing countries was of a 'ski slope'. High tech exporting 'belonged to' the leading OECD countries. The present results might be likened to a gentler 'beginners' ski slope'; competition is real (e.g. Malaysia exports far more high tech than Italy). (Again, we acknowledge that interpretation is not straightforward; much of Malaysia's exports come via multinational companies headquartered elsewhere; however, the data show that the country has moved well beyond the manufacturing platform model of some years ago [Newman *et al*, 2004].)

Since 1987, HTI has pointed toward dramatic broadening of global high tech competition, and it continues to do so. The leading (input) indicators remain strong for the OECD, Asian Tigers and China. Recent rising concerns about the loss of US pre-eminence in research publishing and patenting are only a part of the vital 'Inputs' to technological competitiveness (Broad, 2004). Indeed, it is not a downturn in US research, but an upsurge in that of others, most notably, China. They present more of a mixed picture for other industrializing nations.

Our model suggests that INPUT-1993 should anticipate TS-2003 or perhaps, more specifically, the rate of change in inputs in 1993 should anticipate the rate of change in standing in 2003. The model was devised to anticipate which industrializing nations would be most apt to become stronger export competitors. We leave this as an exercise for the interested reader. We refer the reader to the website and selected references provided for further exploration into how the four separate input indicators appear to influence later technological standing. However, looking ahead, we would suggest a country's present INPUT as a rough pointer toward future prospects. In this regard, note the countries with high INPUT-2003:

- USA — a dominant leader in TS, and in INPUT, suggesting bright prospects
- Japan — slipped somewhat, but still by far the second strongest on both TS and INPUT
- Extremely strong INPUT countries — watch for continued competitive gains for Germany, UK,

The Netherlands, Singapore, Taiwan and Canada

- Also very strong on INPUT-2003 — France and Sweden, and (not shown) Israel and Ireland.

What will the future bring in high tech export competition? Our International Indicators Panel — the experts whose opinion is incorporated into the indicators — provides an interesting perspective. Figure 2 shows its average ratings for each of our 33 countries on present competitiveness, and anticipated competitiveness in 15 years. As scaled here, values range from ‘10’ — essentially no capability, to ‘50’ — their products considered technically advanced, ‘state of the art,’ in international markets.

The message is stunning. In HTI-2003, excepting Japan and a few Western European countries, every country is expected to increase its high tech export capability over the next 15 years. The projected gains are large for all groups except the most highly industrialized countries.[3] This optimism does not show dampening in conjunction with the recent bursting of the ‘technology bubble’ (e.g. demise of the dot.coms, staggering drop in the NASDAQ index).

The focus of these HTI indicators is on manufactured products for export. As the world shifts increasingly into an ‘information economy’, we also want to track economies that are strong in information-intensive activities. We are in the process of reformulating HTI to place far more weight on these factors likely to reflect in high tech services (Young, 1996), as well as knowledge-intensive products (Newman *et al*, 2004). We anticipate reporting on the ‘new’ HTI in conjunction with generation of these indicators for use by the US National Science Foundation as it prepares *Science and Engineering Indicators 2005*. We are gathering a range of additional statistical measures and have reformulated the ‘new’ HTI. We will continue to compute HTI for 2005 as per the series reported here, but will also compare with the new formulation.

Notes

1. [To come]
2. HTI are generated every three years. In 2003 we just redesignated them using the year in which they are published (2003) instead of the year in which most data are collected (2002). Also, we note that many of the statistical measures lag, so the data years used vary somewhat on individual measures, and even for particular countries on a given measure. Anyway, the span from 1993 HTI to 2003 HTI is really nine years.
3. There is a marked ceiling effect. For instance, Japan, currently gauged at about 47 can at most be projected to increase 3 points to the maximum of 50.

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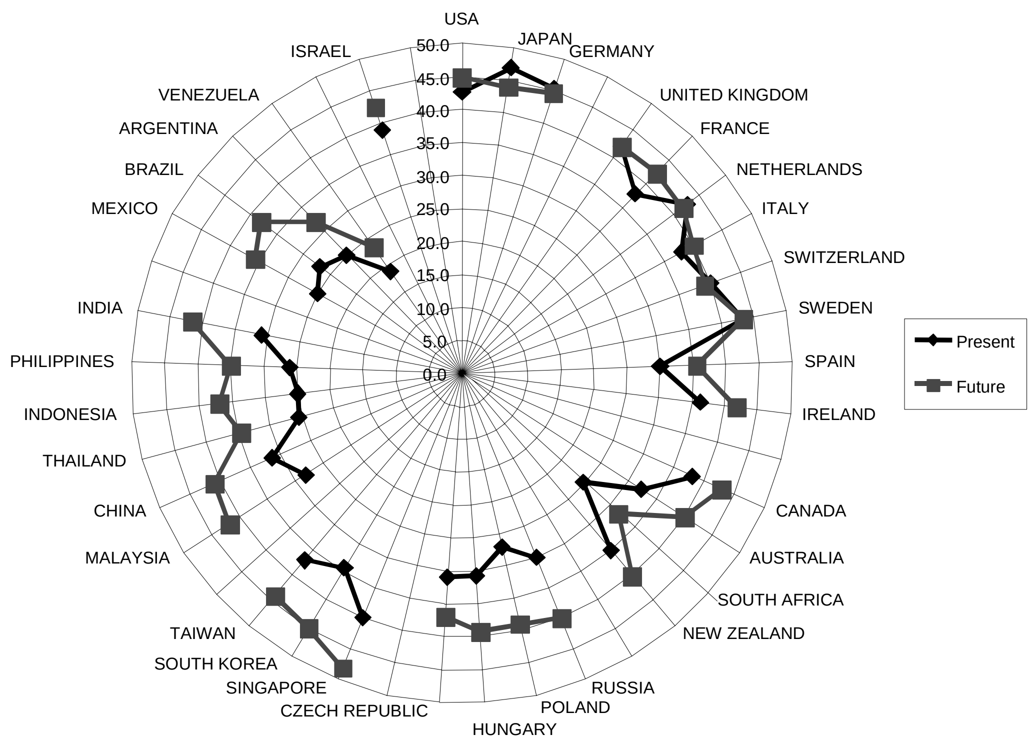

Figure 2. Present vs. future (15 years): overall high tech production capability 2003

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